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(54) Use of dynamic masks for object manufacture

(57) A dynamic mask (spatial light modulator) is used to produce a defined amplitude pattern in the imaging or Fourier plane of a lens system for application to object manufacture and rapid prototyping. The polarisation of an illuminating optical wavefront is amplitude or phase modulated by the spatial light modulator after transmission through, or reflection from, a polarising element. The pattern so generated is imaged or Fourier transformed to a photosensitive medium in order to create a specified level slice of the 3-D model or component under construction. Alternatively, a phase pattern is calculated and written to a phase modulating spatial light modulator. The pattern is calculated such that when optically Fourier transformed, an intensity pattern is generated in the back focal plane of the lens system. Derived from its CAD solid model, this will correspond to a given cross-section through the component or prototype under construction.

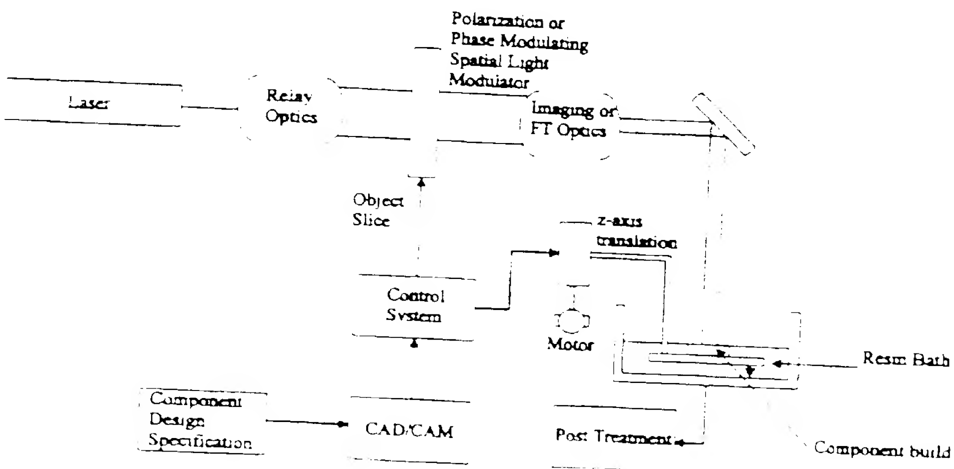

Figure 2

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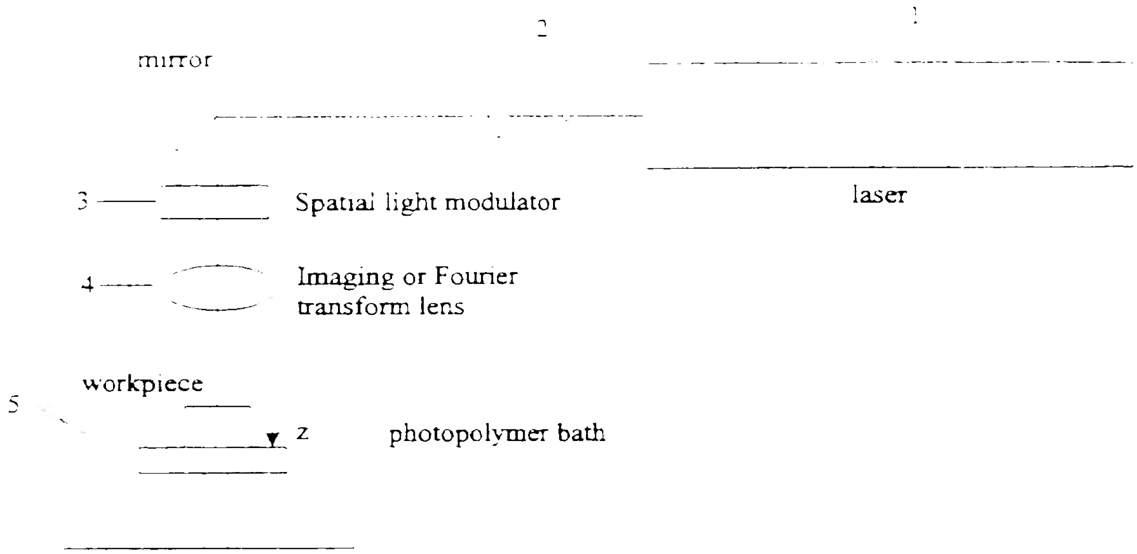

Figure 1

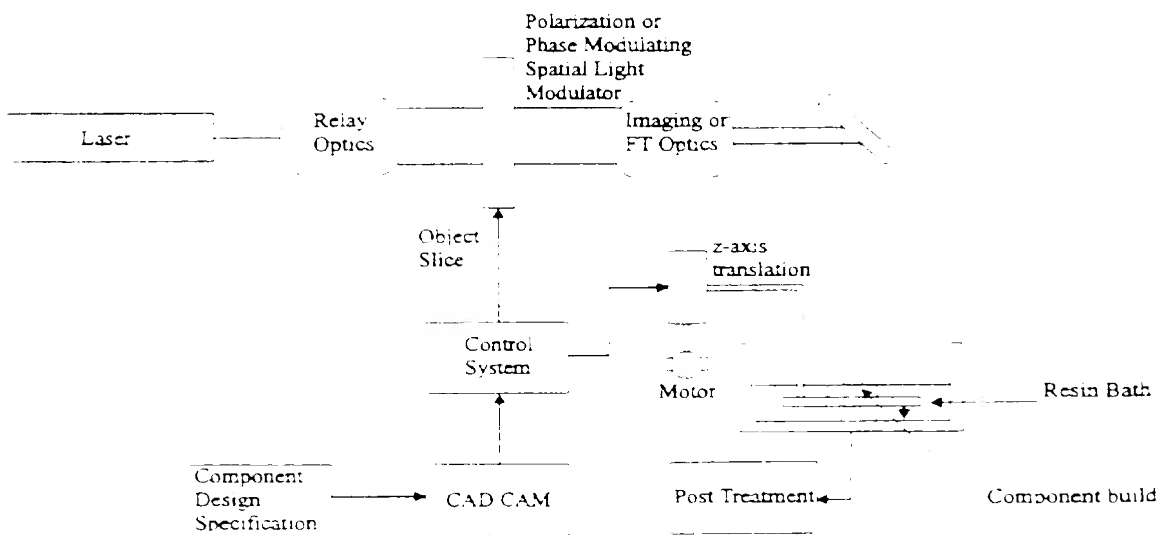

Figure 2

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Use of dynamic masks for object manufacture

The invention relates to the use of a Spatial Light Modulator (SLM) to produce a defined amplitude pattern in the imaging or Fourier plane of a lens system for application to object manufacture and rapid prototyping.

Currently, laser scanning systems are used to write, one data point at a time, CAD model level slice data onto the surface of a photopolymer so as to induce a photopolymerisation reaction and create a solid layer of polymer corresponding in shape to the component at that level. The laser beam must be raster scanned over the surface in a serial manner which is inherently slow.

The invention described herein employs a dynamic mask, electrically or optically addressed with CAD level slice model data. This modulates an optical wavefront with this information by spatially changing the polarisation or phase of the wavefront such that an amplitude pattern corresponding to the CAD level slice is projected onto the surface of the photopolymer or other substrate. The model or component is thus built layer by layer into a solid by displaying successive level slices from the CAD model on the SLM and exposing the photopolymer or other medium to the modulated illuminating radiation.

The polarisation of an illuminating optical wavefront is amplitude modulated by the SLM after transmission through, or reflection from, a polarising element. The pattern so generated is imaged or Fourier transformed to a photosensitive medium in order to create a specified level slice of the 3-D model under construction.

Alternatively, a phase pattern (binary or, preferably, multi-level phase) is calculated and written to a phase modulating spatial light modulator (PM-SLM). The pattern is calculated such that when optically Fourier transformed an intensity pattern is generated in the back focal plane of the lens system. This corresponds to a given cross-section through the component under construction which is derived from a CAD solid model of the component for which it is desired to produce the prototype.

To do this, the PM-SLM is illuminated by a TEM_{00} (Gaussian) mode coherent laser wavefront. Uniform illumination of the PM-SLM is not required since the intensity pattern is realised in the reciprocal space. Thus the Gaussian profile of the illuminating beam results in a convolution of the impulse response of the optical system with the generated intensity pattern which will be the Fourier transform of the illuminating Gaussian beam. The wavelength of the coherent wavefront may be from the ultra-violet to the visible dependant on the nature of the photopolymer being used. The phase pattern is determined by an iterative technique such as one of the variations based on the Gerchberg-Saxton algorithm.

The imaging or Fourier plane of the lens system is arranged to be at the surface of, or within the body of, the liquid photopolymer substrate that is photo-polymerised to a solid according to the pattern projected onto its surface. Thus a solid level-slice of the prototype under construction is generated that corresponds to the projected intensity pattern. Z-axis increments of the prototype in the photopolymer bath are carried out

in order to build the entire component layer by layer. Thus, for each layer a new phase pattern is displayed on the PM-SLM and hence a new intensity distribution is generated at the particular z-plane under construction.

A specific embodiment is illustrated in the Figures below. The conventional scanning mirror system is replaced by the SLM projection technique. In Figure 1 a laser 1 passes through beam expansion optics 2 so as to illuminate the spatial light modulator 3. The lens 4 images or Fourier transforms the polarisation or phase modulated wavefront onto the surface of the model currently being constructed such that the desired amplitude pattern is produced at the surface. In this particular embodiment, this is a photopolymerised model immersed in a photopolymer bath. Successive layers are built up by lowering the model into the bath after each layer is photopolymerised. Figure 2 is an overall system diagram showing the data flow links to the CAD system.

Having described the invention the claims are:

1) The use of polarisation modulation, generated by whatsoever means, used so as to generate an intensity pattern when imaged or focused by a lens, to be used for cutting or solidifying a material.

2) The use of a programmable polarisation modulating mask (spatial light modulator) designed so as to generate an intensity pattern as in claim (1), to be used as in claim (1).

3) The use of a programmable polarisation modulating mask as in claim (2), to generate an intensity pattern as in claim (1), to be used in a rapid prototyping and/or manufacturing system using any material process whatsoever in order to generate a solid model layer by layer.

4) The use of a programmable polarisation modulating mask as in claim (2), to generate an intensity pattern as in claim (1), to be used in a rapid prototyping and/or manufacturing system as in claim (3), to solidify a photopolymer matrix containing any material whatsoever in order to generate a solid component object layer by layer.

5) The use of a programmable polarisation modulating mask as in claim (2), to generate an intensity pattern as in claim (1), to be used in a rapid prototyping and/or manufacturing system as in claim (3), to solidify a photopolymer matrix containing any material whatsoever in order to generate a solid object layer by layer.

6) The use of a phase mask, made by whatsoever means, designed so as to generate an intensity pattern when imaged or focused by a lens, to be used for cutting or solidifying a material.

7) The use of a programmable phase mask (phase modulating spatial light modulator) to display a phase profile designed so as to generate an intensity pattern as in claim (6), to be used as in claim (6).

8) The use of a programmable phase mask as in claim (7), to generate an intensity pattern as in claim (6), to be used in a rapid prototyping and/or manufacturing system using any material process whatsoever in order to generate a solid model layer by layer.

9) The use of a programmable phase mask as in claim (7), to generate an intensity pattern as in claim (6), to be used in a rapid prototyping and/or manufacturing system as in claim (8), to solidify a photopolymer matrix containing any material whatsoever in order to generate a solid model layer by layer.

10) The use of a programmable phase mask as in claim (7), to generate an intensity pattern as in claim (6), to be used in a rapid prototyping and/or manufacturing system as in claim (8), to solidify a photopolymer in order to generate a solid model layer by layer.

Amendments to the claims have been filed as follows

1) The use of a phase mask, made by whatsoever means, designed so as to generate an intensity pattern when imaged or focused by a lens, to be used for cutting or solidifying a material.

2) The use of a programmable phase modulating mask (phase modulating spatial light modulator) to display a phase profile designed so as to generate an intensity pattern as in claim (1), to be used as in claim (1).

3) The use of a programmable phase modulating mask as in claim (2), to generate an intensity pattern as in claim (1), to be used in a rapid prototyping and/or manufacturing system using any material process whatsoever in order to generate a solid model layer by layer.

4) The use of a programmable phase modulating mask as in claim (2), to generate an intensity pattern as in claim (1), to be used in a rapid prototyping and/or manufacturing system as in claim (3), to solidify a photopolymer matrix containing any material whatsoever in order to generate a solid model layer by layer.

5) The use of a programmable phase modulating mask as in claim (2), to generate an intensity pattern as in claim (1), to be used in a rapid prototyping and/or manufacturing system as in claim (3), to solidify a photopolymer in order to generate a solid model layer by layer.

The Patent Office

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): B3V(VLK); B5A(ATXP, AD23); H4F(FCP, FAAG)

Int Cl (Ed.6): B23K(26/06); B29C(67/00)

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Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Ya	GB2187855A	Gerber Scientific Inc. - see whole disclosure	1 at least
X,Ya	GB1236224A	R C A Corpn. - see whole disclosure	-
X,Yb	EP0676275A1	Texas Instruments - see deformable mirror device 32 Fig.2	-
X,Ya	EP0329787A1	Tsentralnoe Konstuktorskoe Akad Nauk see phase element 3 and claim 1	-
X,Yb	WO96/00422A1	Hercules Inc. - see programmable mask 34, Fig.1 and page 39 line 24 *et seq*	-
X,Ya	WO89/01841A1	Kuibyshevsky Aviatsionny Inst. see Abstract	-
X,Yb	US5558884A	Omnichrome Corpn. - see col.6 lines 25-54	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art
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